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Wedge-Shaped Reflector of Ions and Ion-Optical Features

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Abstract

The prospects for creation of the new type of laser time of flight mass spectrometer were described. The mass spectrometer is based on usage of a reflecting wedge-shaped mirror as an analyzer of the ions by masses. The analyzer provides time focusing ion by both energy and initial angle divergence of ions from the source. Time focusing is carried out for the ±20% energy range, what is at least 2 times more, than for known ion-optical systems for similar usage. The resolution of the mass analyzer is ~850 for extremely small overall dimensions (~10×10×5 cm).

Keywords: Laser ion source; laser time-of-light mass analyzer; wedge-shaped reflector; ion optics; time aberrations; correction of aberrations

1. Introduction

The ion optics with correction of the time aberration by ion energy of laser mass spectrometer was offered in [1]. For this purpose the Mamyrin reflecting ion mirror was used to reduce time aberration of ions by energy. The ion mirror is to be used in laser TOF mass-spectrometer named LAMAS-10. It will allow to increase the resolution of mass-spectrometer up to several thousands.

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Along with a wedge-shaped ion mirror can be used as the new type independent TOF analyzer. To solve this problem it's necessary to research ion-optical properties of wedge-shaped mirror thoroughly. First of all it concerns to time aberrations by energy spread, initial angle divergence, and initial coordinates.

One variant of the analyzer with wedge-shaped mirror for the laser TOF mass-spectrometer is considered in this article. The analyzer has extremely small overall dimensions at satisfactory resolution. The analyzer can be used for creation of instruments both researching space and technological monitoring. To solve such problems the R=500 resolution is acceptable. So long as the theory for the analysis of wedge-shaped ion mirrors is not yet created, the realization of the intention was implemented using the SIMEON-8-3D standard software package.

2. Ion-optical schema of the analyzer

To research possibilities of a wedge-shaped reflecting mirror as TOF analyzer of laser mass-spectrometer, ion-optical schema (IOS) was designed (see Figure1). Initially the research was conducted with a version of the schema based on a simplified wedge-shaped reflector. Ion-optical properties of IOS were determined with the help of the SIMION-8-3D software [2]. For analyzer next basic requirements were formulated: i) energy spread $-\Delta W=\pm 0.2W_0$; ii) the initial angular divergence of ions – $\alpha=\pm 1^0$; iii) the slit width of the ion source – S_1=0,1mm; iv) analyzer sizes – up to10×10×5cm; iv) resolution – at least R=500.The principle operation of TOF analyzer is as follow. Focusing lens FL ensures the formation of focal spot of laser radiation. Diameter of the spot equals as d_f=30-50μm. Plasma clot is generated due to laser irradiation of an analyzed sample (AS). As result the dense laser plasma is formed. Further plasma expands due to uncompensated space charge. After its weakening by the skimmer and destruction with the help of magnetic field the ion package is formed. In this case ions have practically constant speed [3]. Ion package formed as a narrow beam starts to the wedge-shaped reflector. The reflector consists of a grid (GE) and reflecting (RE) electrodes. For edge electric field correction and optimization a corrective plate CP is set. A deflection angle between electrodes was chosen according to the condition of time ion focusing by energy in the plane of the first dynode of secondary electron multiplier (SEM). Then ion packages separated by mass arrive at the ion detector and a sequence of electric pulses is being formed at the SEM anode as the mass spectrum.

The key characteristics of laser TOF mass analyzer are resolution and accuracy of elemental analysis. For the analyzer having a small size the ion flight time from sample to the detector is also small. That is why it's necessary to ensure high quality of time focusing to obtain resolution at the level of R~500. But it's possible to do only if full information about analyzer ion-optical parameters is known. First of all these ion-optical parameters include time aberrations by: i) energy of ions; ii) the initial angle divergence of ion packages; 3) the initial coordinate spread of ions.

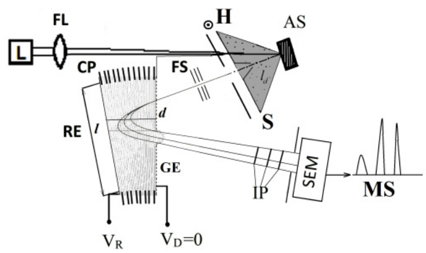

Fig. 1. Ion-optical schema of laser ion source with wedge-shaped reflecting mirror. $l=200$ mm , $d=41,5$mm

The quality of the ion time focusing by energy has significant importance. It should be noted that for realization of a qualitative element analysis, i.e. for receiving satisfying accuracy it's necessary to scan and accumulate mass spectra for wide range of initial ion energy. In [4] it is shown, that for optimal laser beam power density of (q~(3-5)·10^9 W/cm^2), the energy range of initial ion energy is approximately 40 - 300eV. Therefore the TOF analyzer should provide time focusing in a wide range of ion energies. To scan of a mass spectrum for differ ion energies it is need produce changing of the reflecting electrode potential. Because in scanning process the ions of different energy spread will be detect by SEM, therefore different absolute scanning step is recommended to be chosen.

3. Time ion aberration by energy

To determine the time aberration for $^{64}Cu^{+}$ ions by energy the geometry with the $\psi=10^{0}05$`deflection angle of wedge-shaped mirror was used. The input grid electrode was initially chosen as flat one. In this case the time aberration by energy is δt=19 ns. Minimization of δt was carried out by setting defocusing lens in the exit area of the ion package from the grid electrode. This operation allowed to minimize the time aberration to 1.2 ns (Figure 2). Then the resolution equals of $R=t/2\delta t\approx1400$.

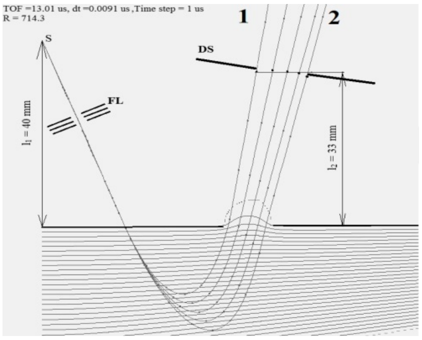

Fig. 2.Time ion focusing at W_0=50 eV, 1 – W=40 eV. 2 – W=60 eV

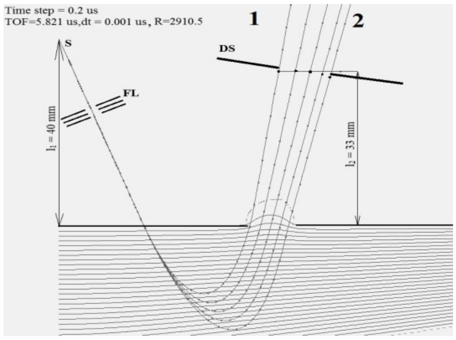

Fig. 3. Time ion focusing at W_0=250 eV, 1 – W=200 eV. 2 – W=300eV

The analysis of the time of flight dependence and the time aberration by energy shows following. The ion flight time decreases in proportion to inverted ratio of a velocity, i.e.:

$$t=\sqrt{W_0/W}\cdot t_0 \tag{1}$$

where t_0– the ion time flight at W_0=50eV, W – arbitrary value of ion energy. As for time aberration the following ratio is appropriate:

$$\delta t=\left(W_0/W\right)^{3/2}\delta t_0 \tag{2}$$

where δt_0 – value of the time aberration at W_0=50eV.
Considering equations (1) and (2) the relation resolution is:

$$R=(W_0/W)\cdot R_0, \tag{3}$$

where R_0 – resolution at W_0=50eV.

These estimates allow to come to an important conclusion. The influence on initial ion energy mostly affects at low ion energy. Then reducing of scanning range of ion energy to range of 100-300eV can significantly to improve the resolution of considered TOF analyzer. The negative factor is an excluded part of ions from detection process and consequently some reduction of accuracy of elemental analyses, mostly for light elements. This reduction is partially aligned by circumstance that at the "edges" of the ion energy distribution, their intensity is greatly reduced one. The other way of resolution correction for ions with reduced energy is applying mathematical processing.

4. Time aberrations be initial ion angle divergence

One important reason for the formation of time aberrations is distortions duration ion packages due to differences in time of flight of ions with the same energy on the trajectories of different lengths. Therefore research of such distortion is rather important problem. The simulation of ion movement having the W_0=50eV energy (Figure 4) has shown, that values δt_0 for such configuration of ion-optical system in the area of time focusing follows to the law:

$\delta t_0 = 5.157 \cdot 10^3\ 2\alpha$ μs. (4)

For divergence α=0.017rad (~1^0) we have δt_α=180 ns. With such angular divergence the limitation of resolution equals R_α~70. To solve this problem is possible only by providing time ion focusing by the initial ion divergence, at least, the first order one. For this purpose a single lens between the ion source and the reflector was set. With the help of this lens it's possible to correct ion paths relatively to the average path. When choosing the lens with arm length l_1=21.2 mm, l=131.0 mm (focal distance is F=18.2 mm) complete coincidence both the trajectories of divergent paths connected with the angles and average ion path is reached. The time focusing of the first order by the angles is realized. Duration of ion packages for identical other parameters is equals of δt_α=0.2 ns, and resolution limitation is R_α=32750.

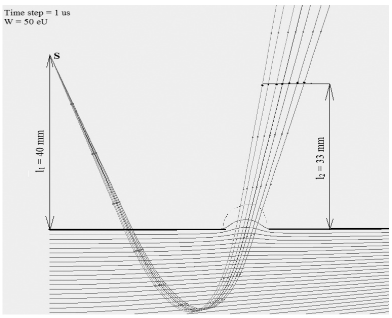

Fig. 4.Trajectory of ions with angular divergence 1 – α=0. 2 – α=+1^0, α=-1^0

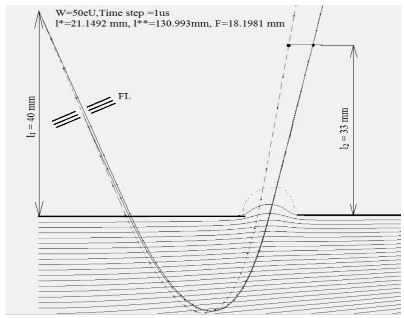

Fig. 5.Correct lineal aberration with the help of this lens 1 – α=0. 2 – α=+1^0, α=-1^0

Time aberration by ion initial coordinates

To estimate time aberration by ion initial coordinates, the coordinate spread was chosen in ranges=±0.05 mm (i.e. for full width of output split for laser ion beam one equals S_i=0.1 mm). The choice of such width for laser ion sources quite sufficient due to high density of generated ion package from laser plasma. When time aberrations by initial coordinate spread are researching it's necessary to take into account the path distortion for ions passing through a single lens. The simulation of ion motion gives the spread of ion time of flight at level δt=2 ns, which gives to estimation of resolution limitation equaled as R~4250.

Total resolution

Total resolution can be calculated by the method, described in [1]:

$$\frac{1}{R_\Sigma} = \sum_{i=1}^{3} \frac{1}{R_i}, \tag{5}$$

where $R_1 = R_W = \frac{t}{2\delta t_W}$, $R_2 = R_\alpha = \frac{t}{2\delta t_\alpha}$, $R_3 = R_s = \frac{t}{2\delta t_s}$. As final we obtain total resolution of TOF analyzer with the wedge-shaped ion mirror as follow R_Σ=850.

Conclusion

In the article it was considered the new ion-optical schema of the TOF analyzer and prospects of development of a new laser TOF mass-spectrometer based on the wedge-shaped reflector. It's shown that application of the wedge-shaped reflecting mirror has a number of advantages. A wedge-shaped mirror provides a compensation of time aberration by energy both 1-st and in partly of 2-nd order. There's also an important positive property of the analyzer which concludes in possibility of time focusing providing in wide energy range equals as ±20%. It allows making detection and registration almost all ions when mass-spectra are scanning. It is important for increasing both mass spectrometer accuracy and sensitivity one. In addition the number of scan cycles decreases, when energy spectrum once passes in a process of mass-spectrum scanning. The last property makes it possible to increase the rapidity of this method when elemental analysis is carried out. Another advantage of the TOF analyzer on base of the wedge-shaped mirror is connected with extremely small overall dimensions in comparison with analyzers of the same purpose and resolution.

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